MSFC Solar Instrumentation Group

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NASA Marshall Space Flight Center

Sounding Rocket Instruments at MSFC

Hi-C I (J. Cirtain, PI)
Flew from WSMR on July 11, 2012
Hi-C II (J. Cirtain, PI)
Flew from WSMR on July 25, 2016 – In-flight anomaly
Hi-C II' (A. Winebarger, PI)
Proposed launch Spring, 2018

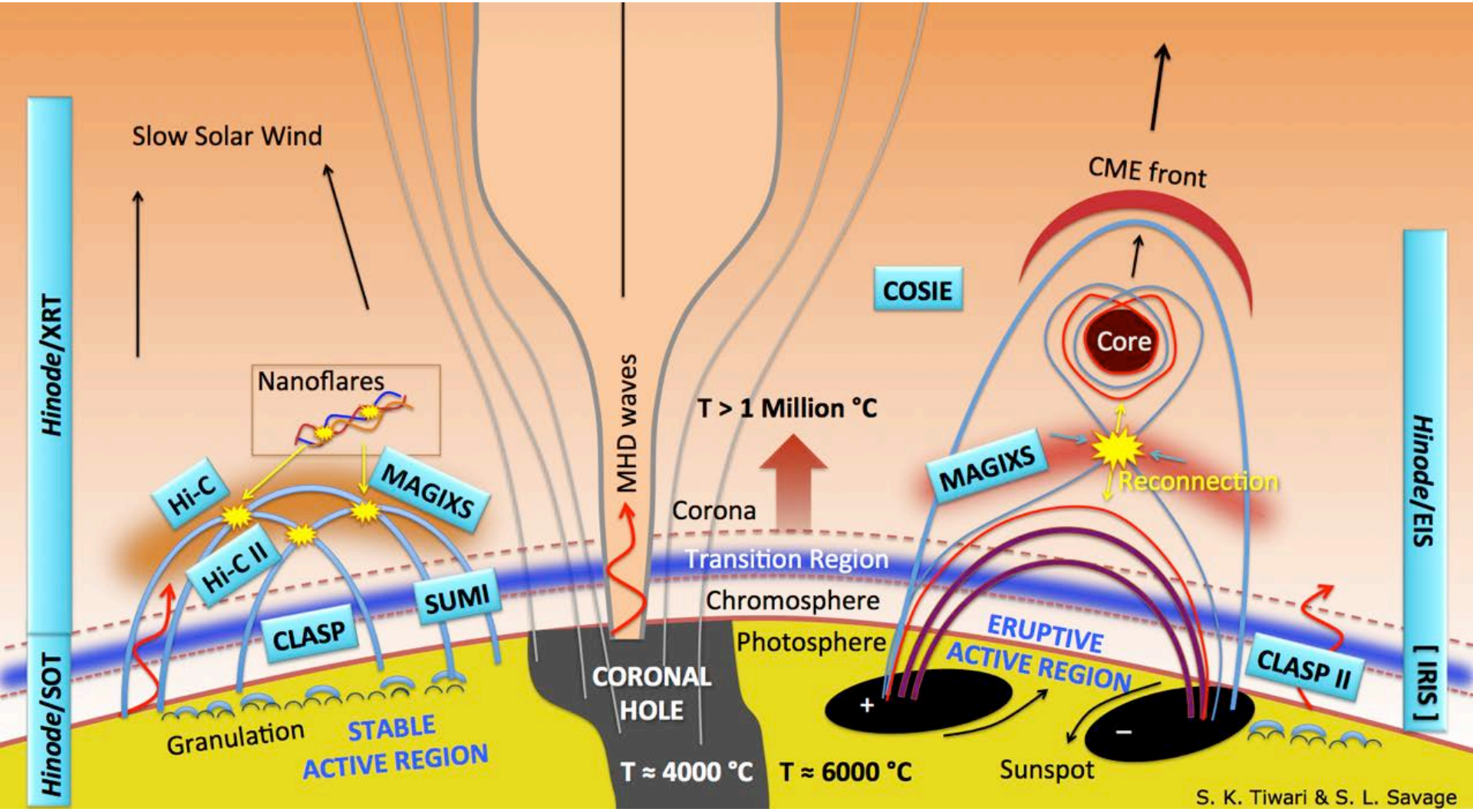
CLASP I (A. Winebarger, PI)
Launched from WSMR on September 3, 2015
CLASP II (D. McKenzie, PI)
Proposed launch Spring, 2019

MaGIXS (A. Winebarger, PI)
Proposed launch Summer, 2018-19

ESIS (A. Winebarger, Co-I & K. Kobayashi, Co-I)
Proposed launch Summer, 2018

FLOWN
FUNDED
PROPOSED

Sounding Rocket Instruments at MSFC

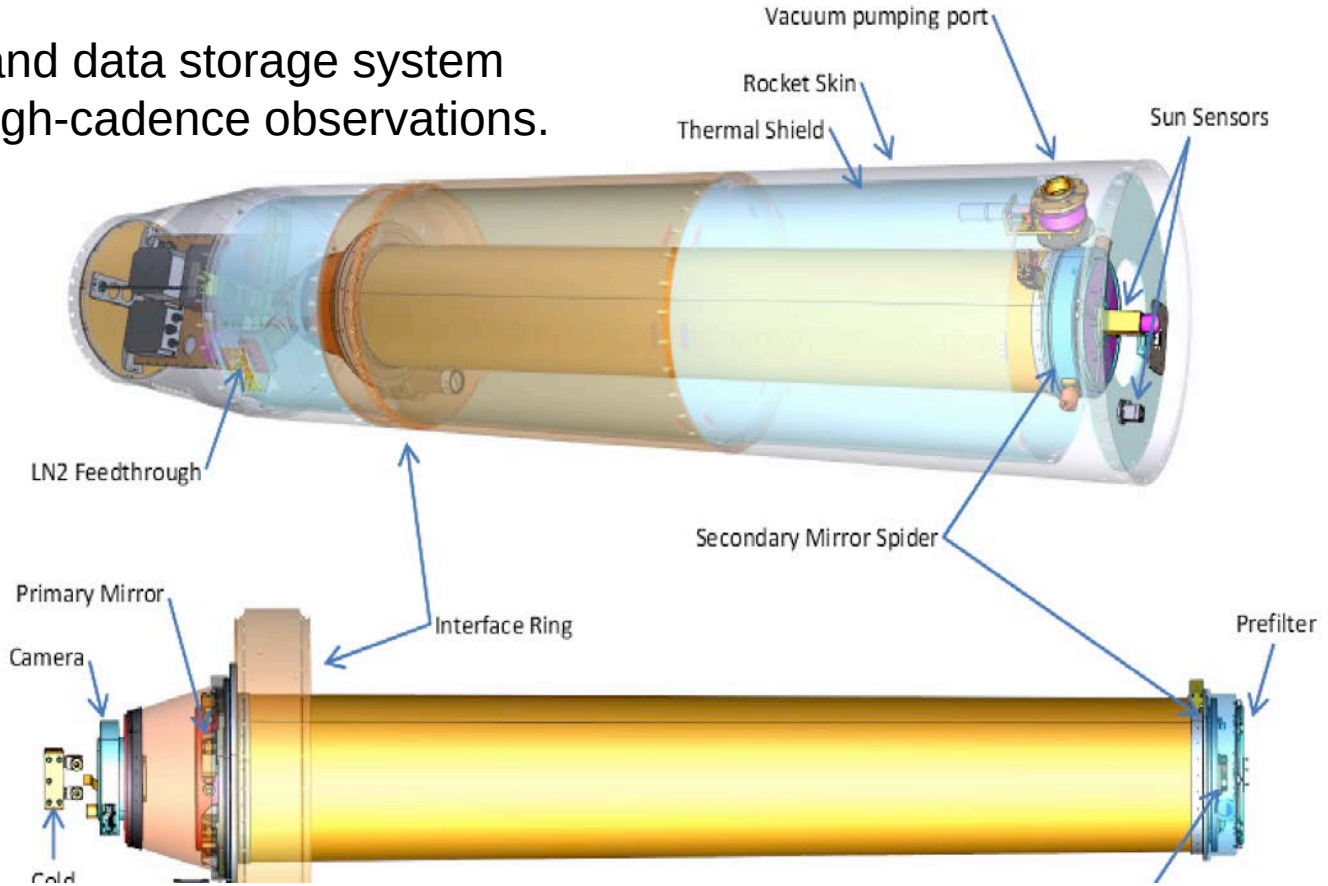


High-resolution Coronal Imager (Hi-C)

Telescope design capable of ~150 km (~93 miles) spatial resolution!

Pointing stability necessary to achieve resolution goal.

Image readout duration and data storage system capable of maintaining high-cadence observations.



Hi-C

Hi-C Launch
White Sands, NM
July 11, 2012

Hi-C recovery team

Hi-C rocket with parachute

Hi-C

Active Region 11520
July 11, 2012

24 publications for 5 minutes of data!

Science highlights:

- Braided loops triggering energy release through magnetic reconnection (*Cirtain et al. 2013, Nature*)
- Subflare triggers
- Nanoflare heating
- Loop sub-structure
- Moss dynamics
- Penumbral jets
- Flows along filament threads
- MHD waves

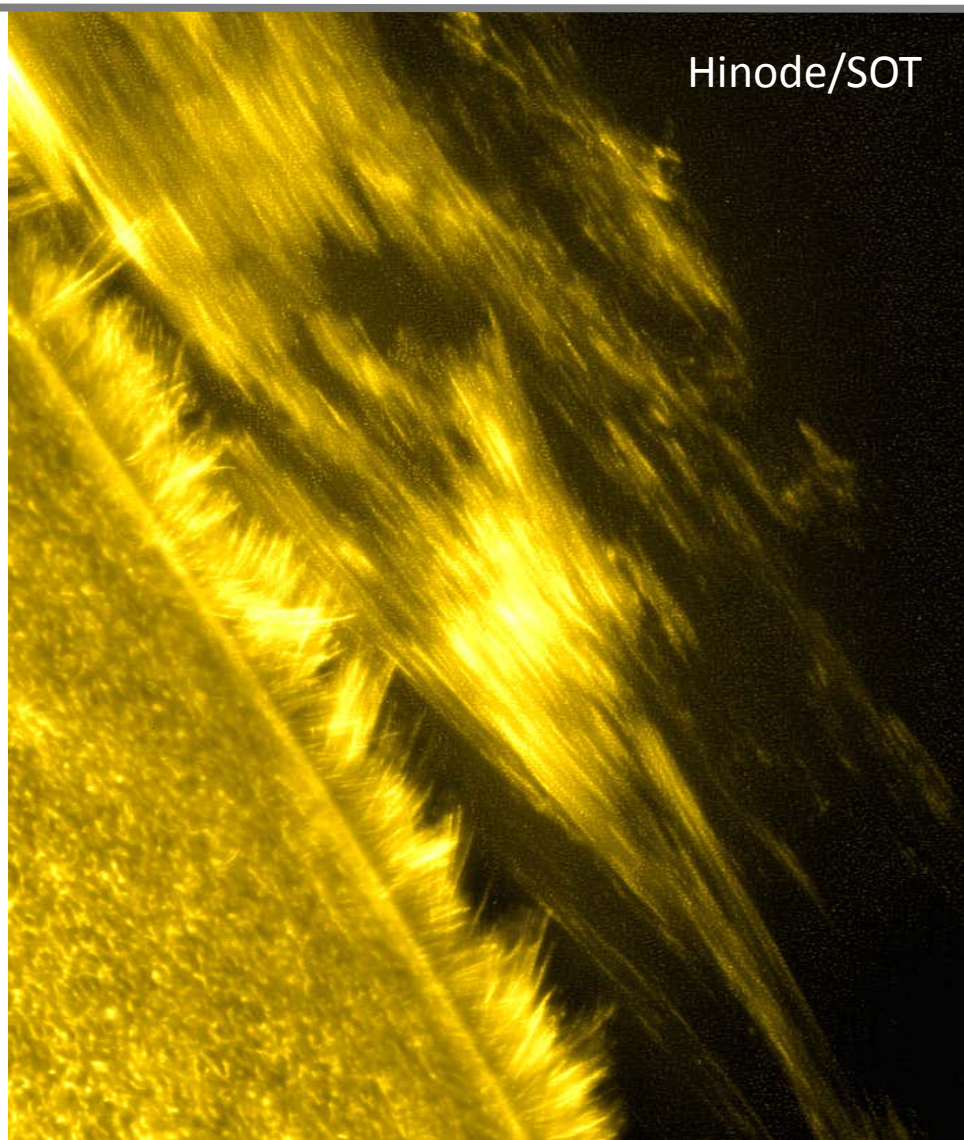
Hi-C II

Hi-C II(‘) will explore the important Chromospheric-Coronal Connection by targeting specific candidates likely to contribute to coronal heating:

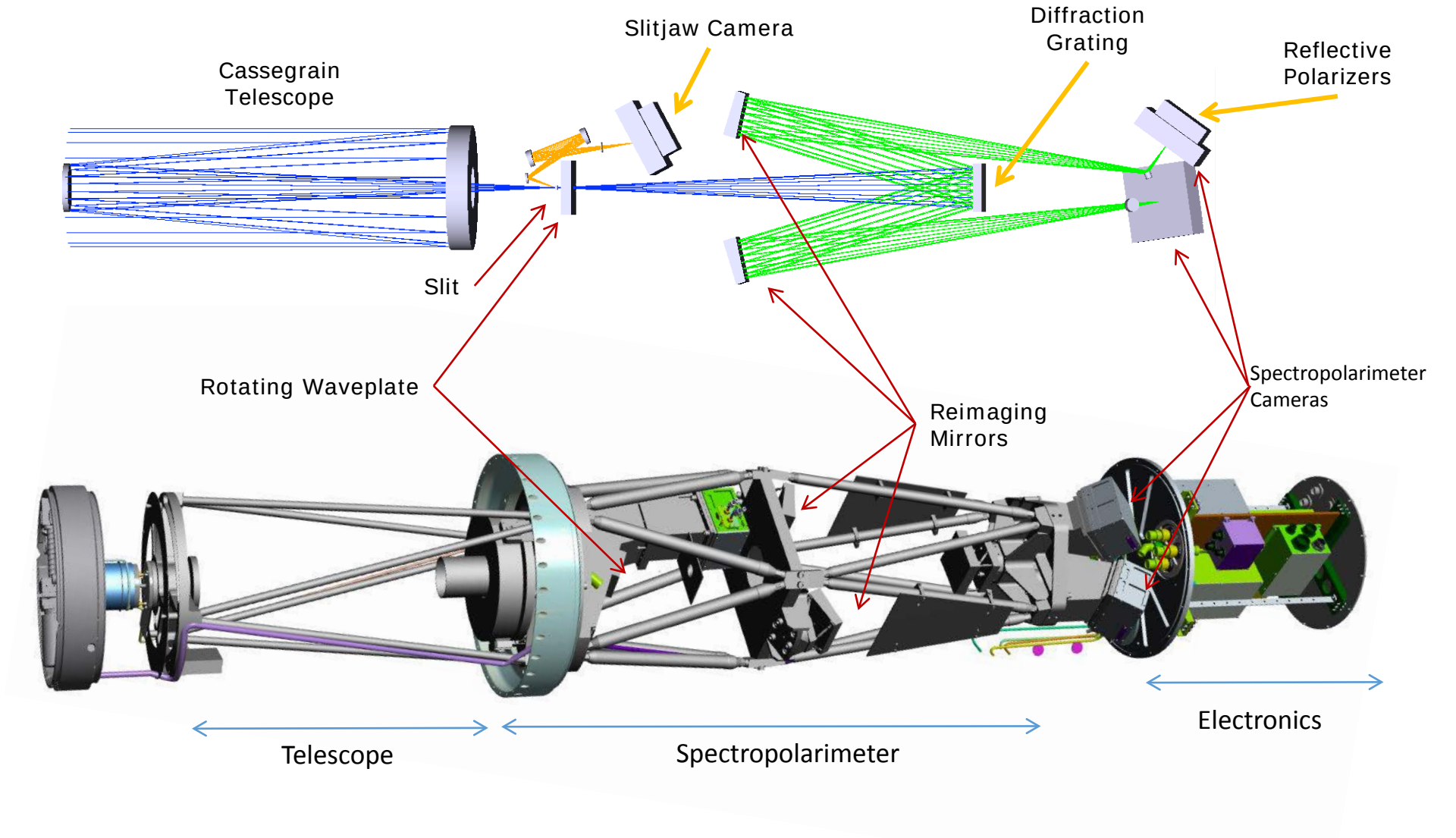
1. Type II spicules
2. Hot active region core loops

Updates for re-flight:

- Cooler bandpass centered on 173 Angstroms
- Significant improvement in camera quality (cameras for this instrument being developed concurrently for other instrumentation where low noise is critical)



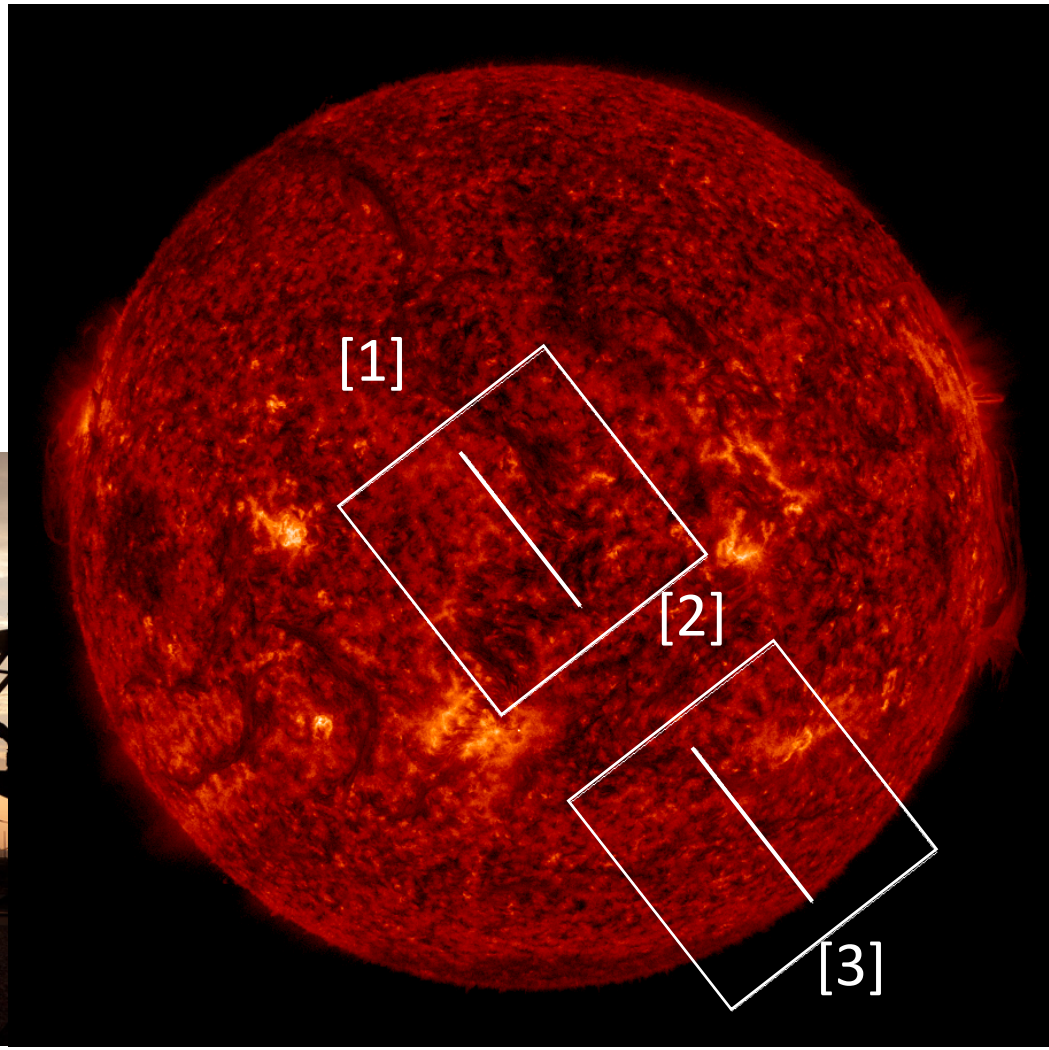
Chromospheric Lyman-Alpha Spectropolarimeter (CLASP)

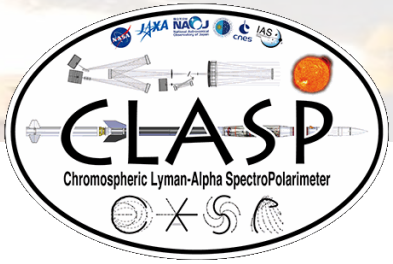


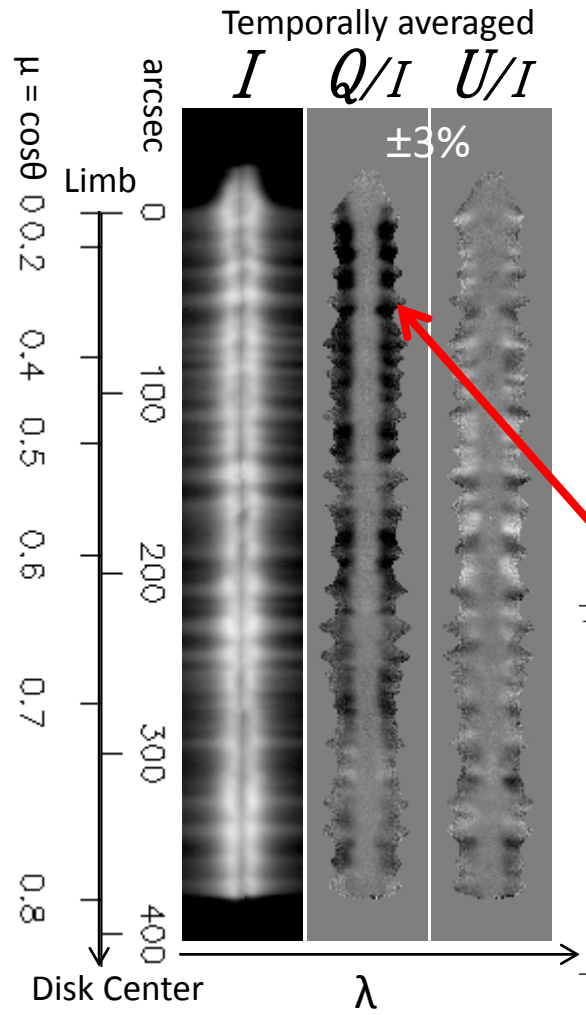
Objective: Use the polarization to infer the chromospheric thermal structure and magnetic field.

- Requires accurate calibration
- Requires advanced theoretical modeling for interpretation

Launched September 3, 2015

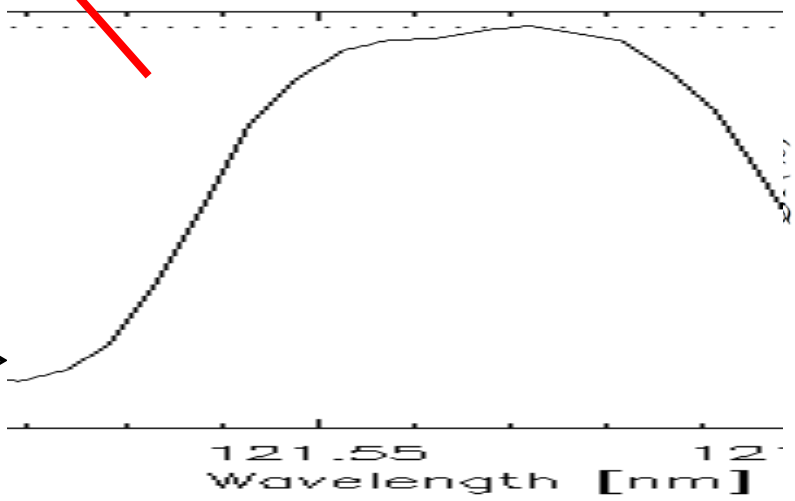


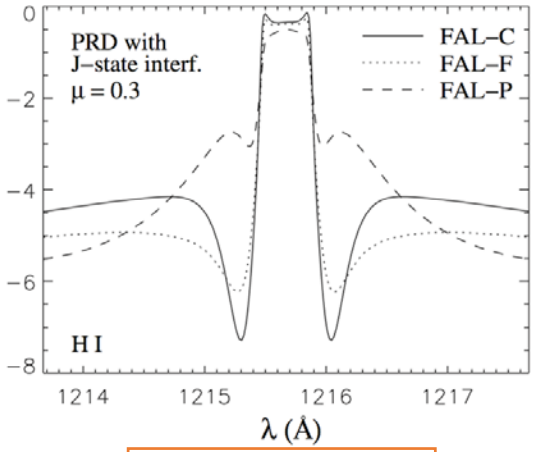

CLASP
Chromospheric Lyman-Alpha SpectroPolarimeter



Further calibrations/investigations are required, but the initial results are…

- **A few %** of polarization in the wing, and **a few of 0.1 %** in the core.
- A clear **C-to-L variation** in the wing of Q/I.
- Small-scale structures along the slit.
- Q/I profile is essentially **consistent with the model prediction**.
- This Hanle effect is the only way to consistently measure the magnetic fields everywhere in the chromosphere.





Belluzzi et al. 2012

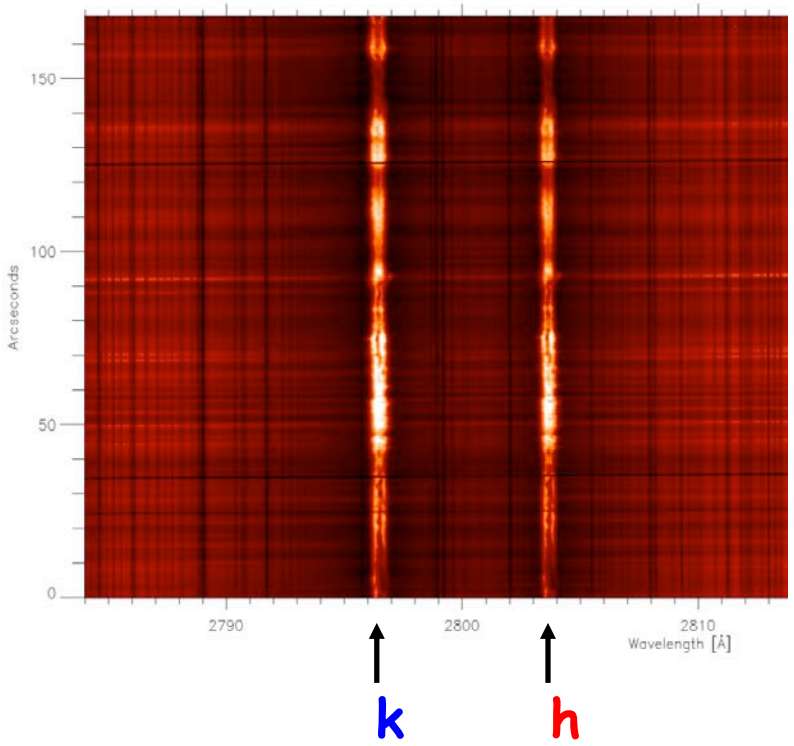
CLASP
Chromospheric Lyman-Alpha SpectroPolarimeter

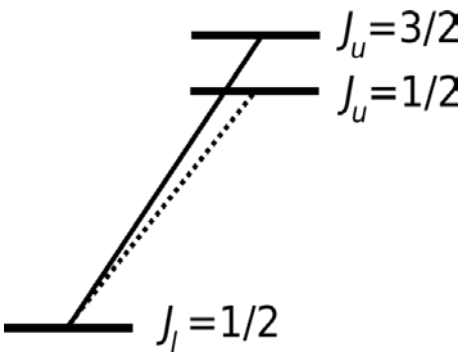
2

Proposed to fly in Spring 2019.

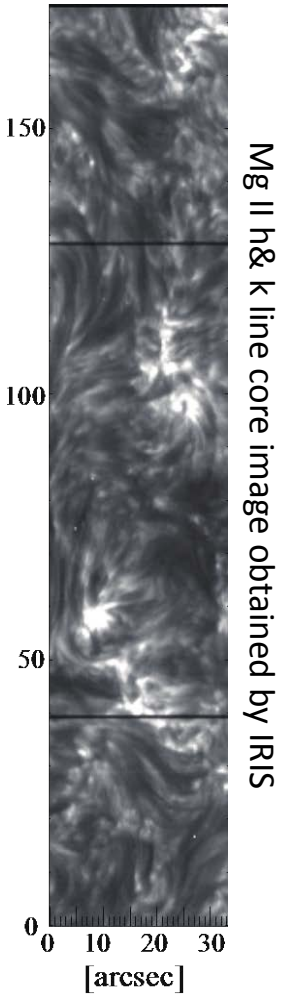
CLASP 2 to change the wavelength to Mg II h&k, another set of magnetically sensitive spectral lines in the UV at ~ 280 nm.

Need to explore multiple lines to determine which is best for routine measurements….





Observing target: QS and plage (if available)



The Marshall Grazing Incidence X-ray Spectrometer (MaGIXS)

Patrick Champey

UAH/NASA MSFC ST13

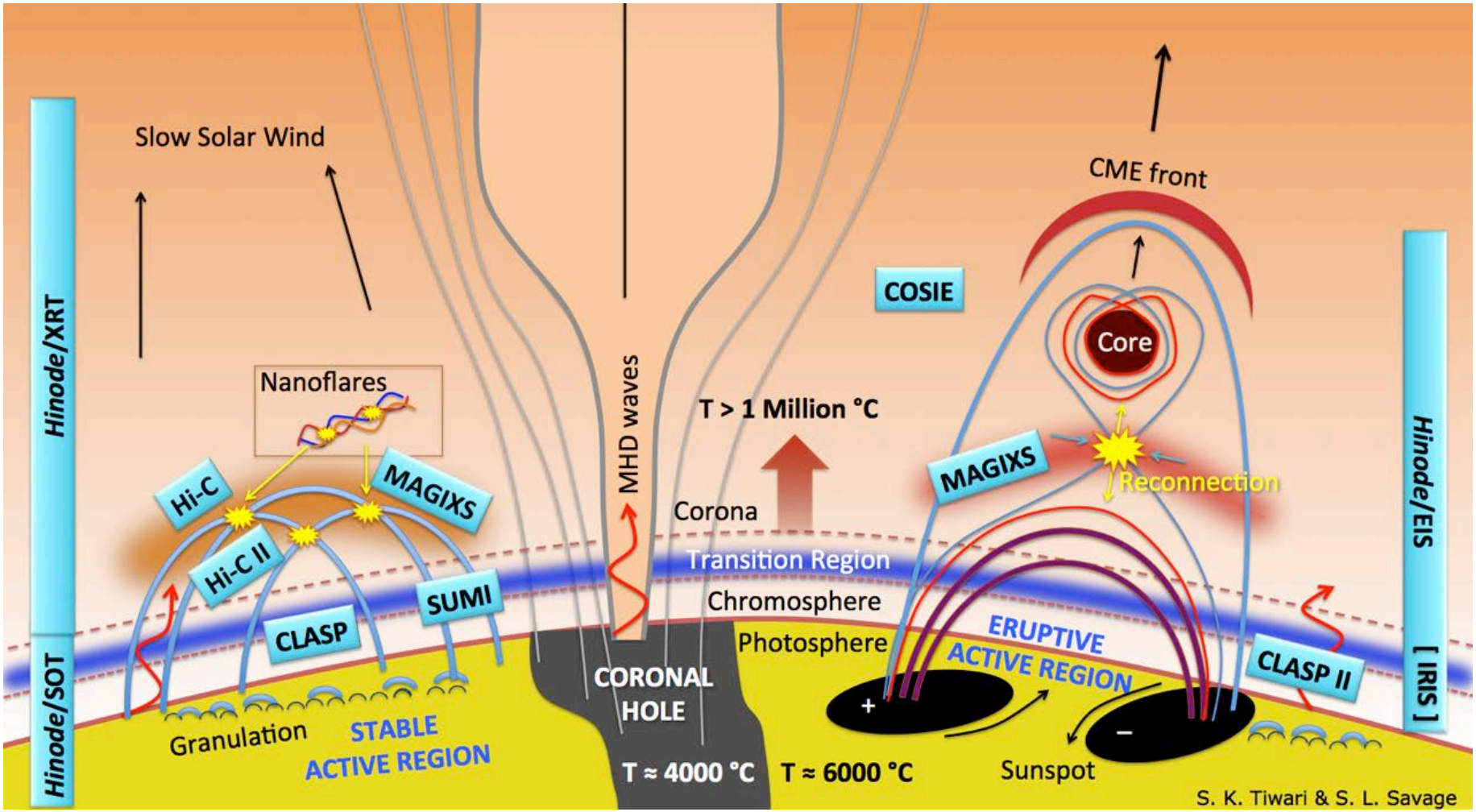
Overview

- Motivation & Science Goals
- Optical Design
- System Error Analysis & Error Budget

Motivation behind MaGIXS

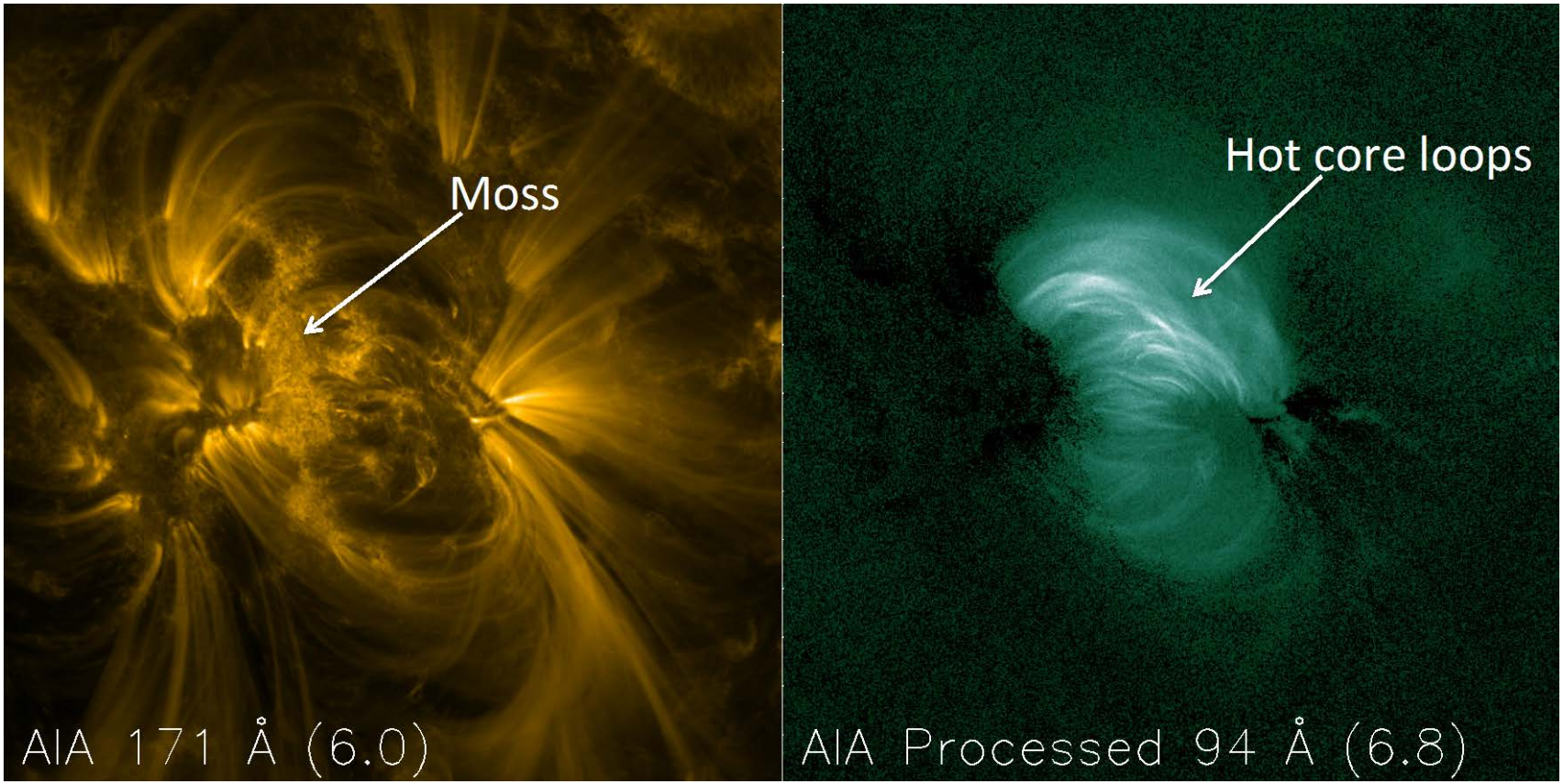
- One of the most interesting phenomena in solar physics is the heating of the sun's corona.
  - Temperature varies from 6000K on the photosphere to 1MK in the corona
  - It is still very much a mystery as to why this occurs
  - Leading hypothesis suggest many small scale events contribute to this phenomena
- We study this phenomena not only to explain these observations, but to broaden our knowledge of the fundamental physics of plasma dynamics
  - Thermal and radiative heat transfer
  - Influence of strong magnetic fields on hot, low-density plasma
  - Magnetic reconnection
  - Wave dissipation
- MaGIXS will observe high-temperature, low-density plasma
  - Differentiate between low- and high-frequency heating in active region core structures, eg. Loops, by analyzing several high-temperature emission lines
  - Ascertain information about the origin of the heating – does the observations suggest nanoflare heating, or wave dissipation, or a combination of both, etc.

The big picture…

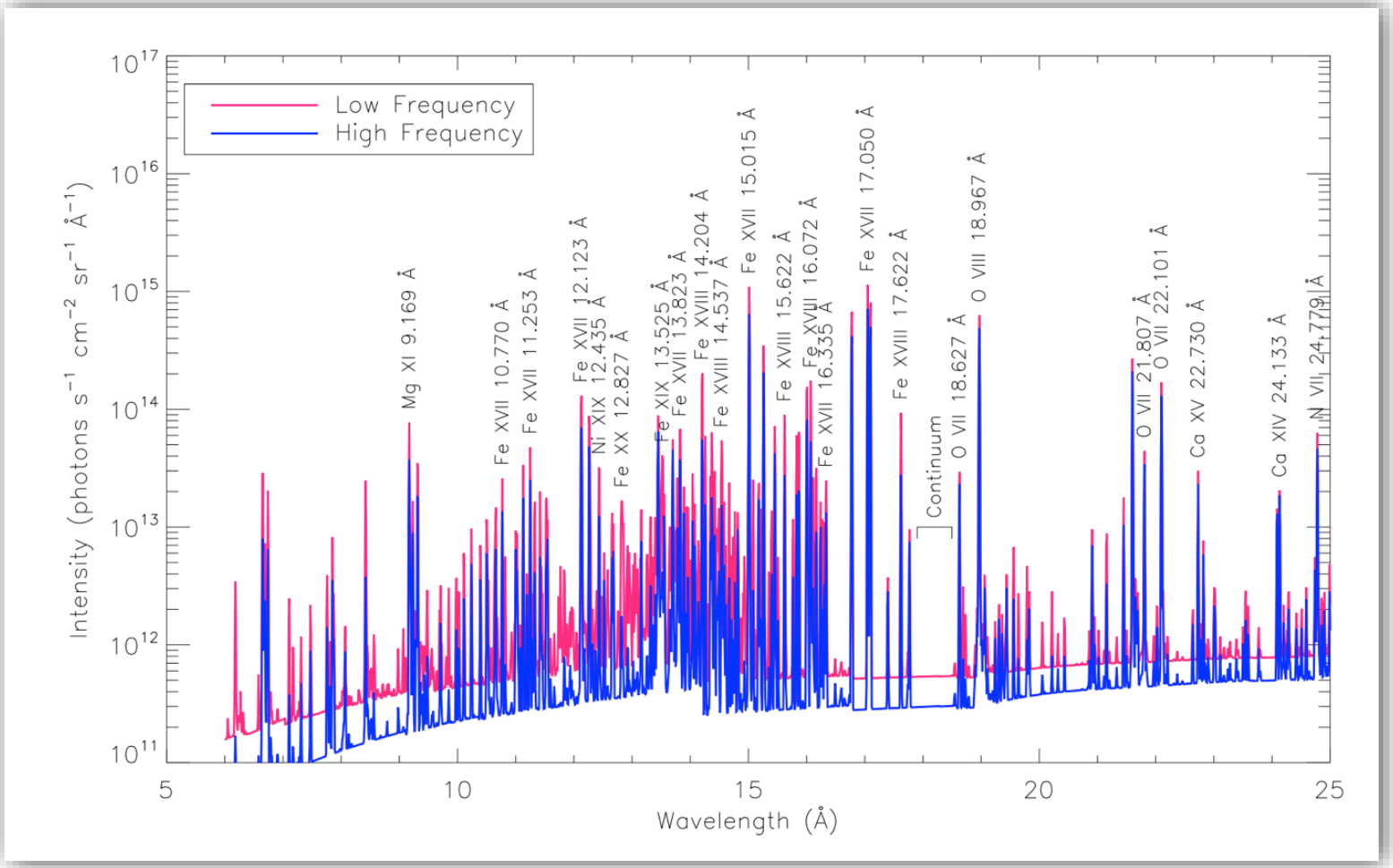


MaGIXS observational target

Science Goal: Determine the frequency of heating in active region cores.
Is heating sporadic (nanoflares) or frequent (waves)?

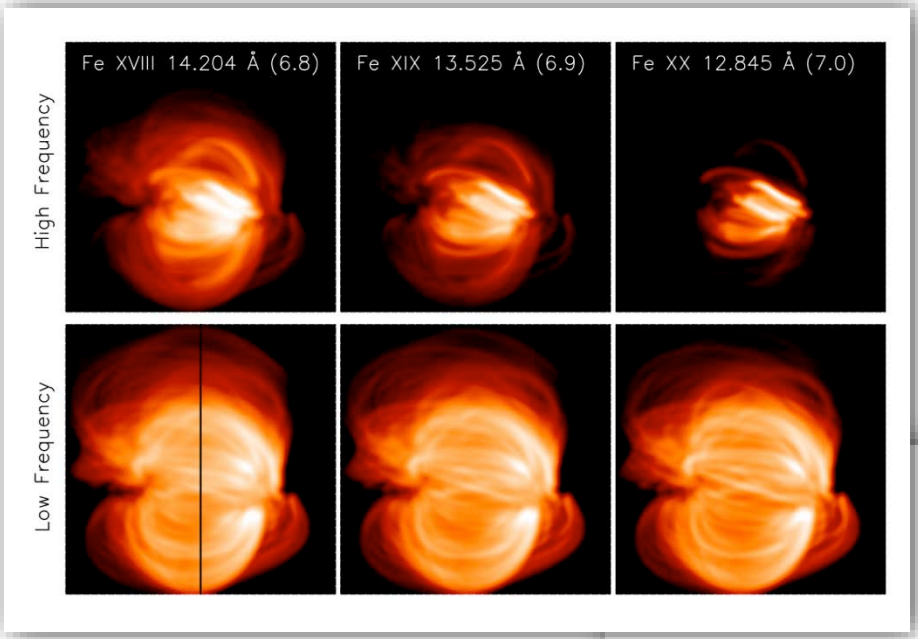


Simulated spectrum



Simulated spectra from a single spatial position along the MaGIXS slit.

Simulated active region core



Simulated active region core
using 0-D EBTEL:

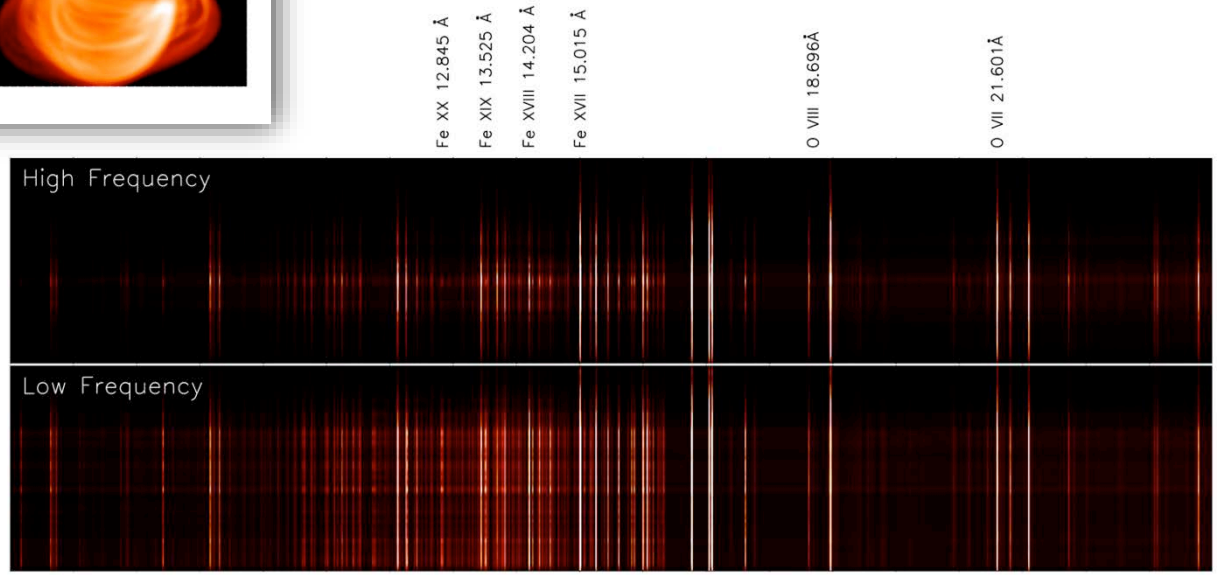
- Random heating events
- Heating event cadence 1575 s versus 6300 s

Expected emission quite different at higher temperature lines.

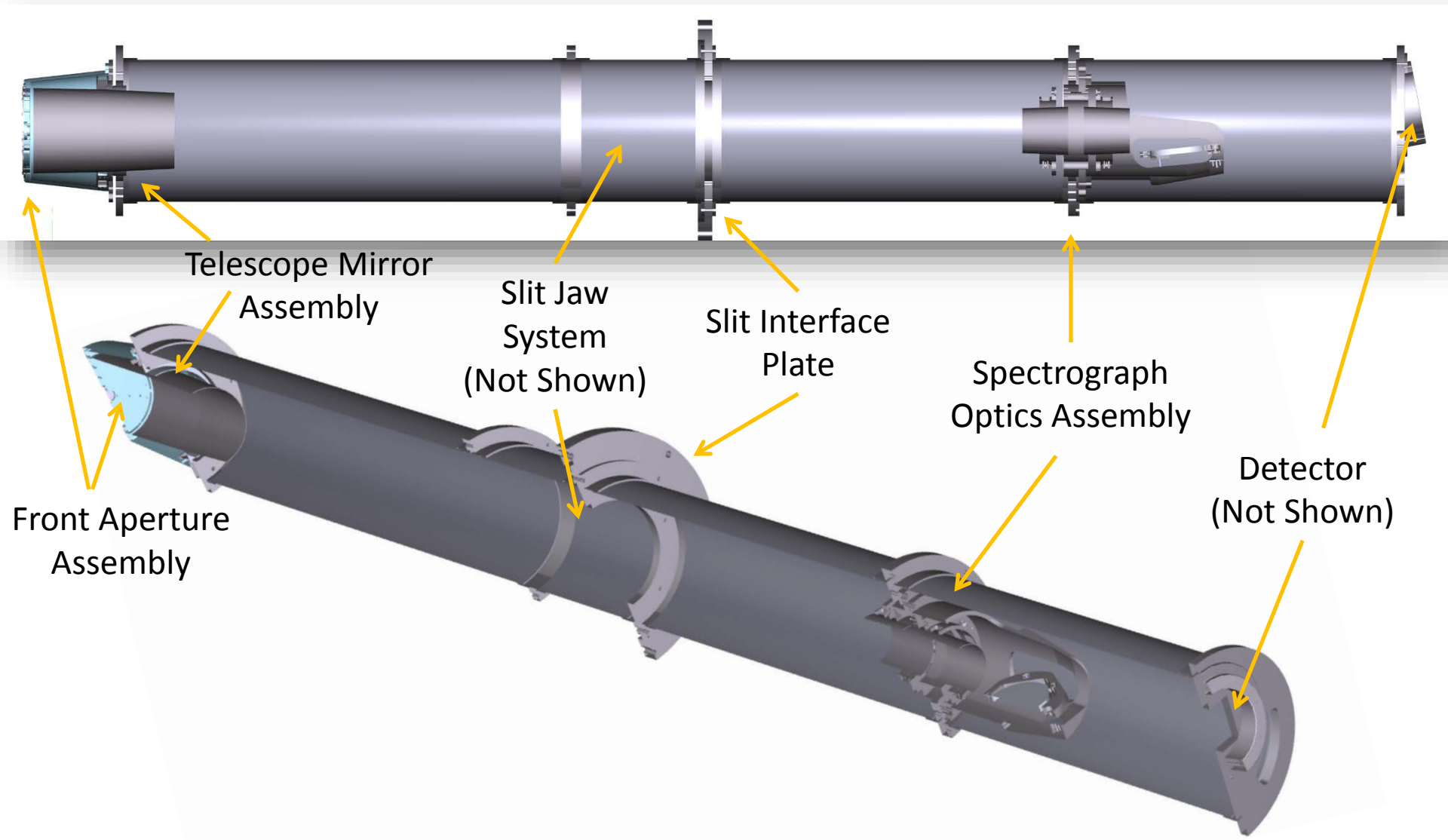
Simulated MaGIXS spectra

Biggest difference in Fe XX (12.845 Å).

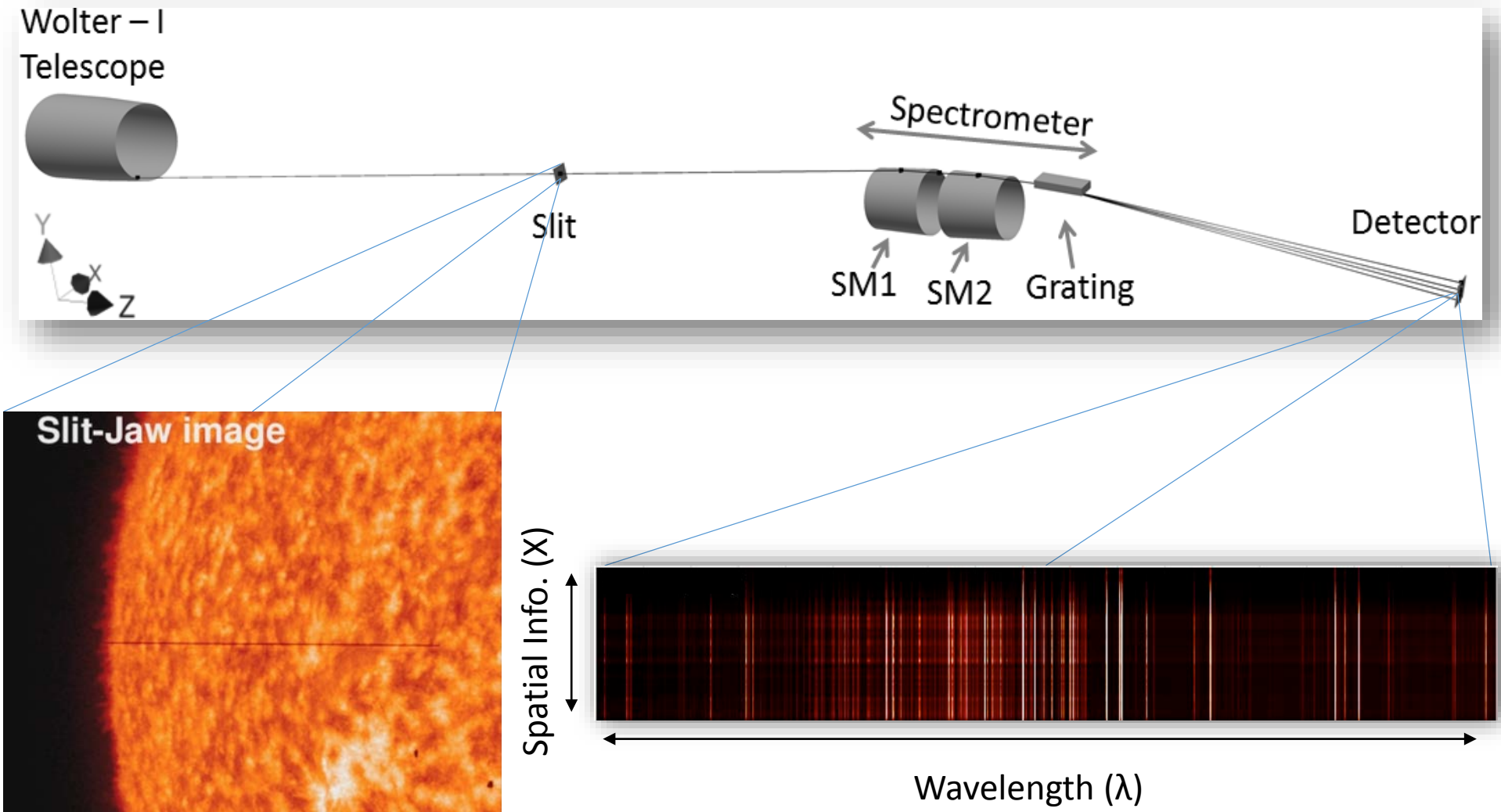
Multiple high temperature spectra lines necessary for interpretation.



Payload concept



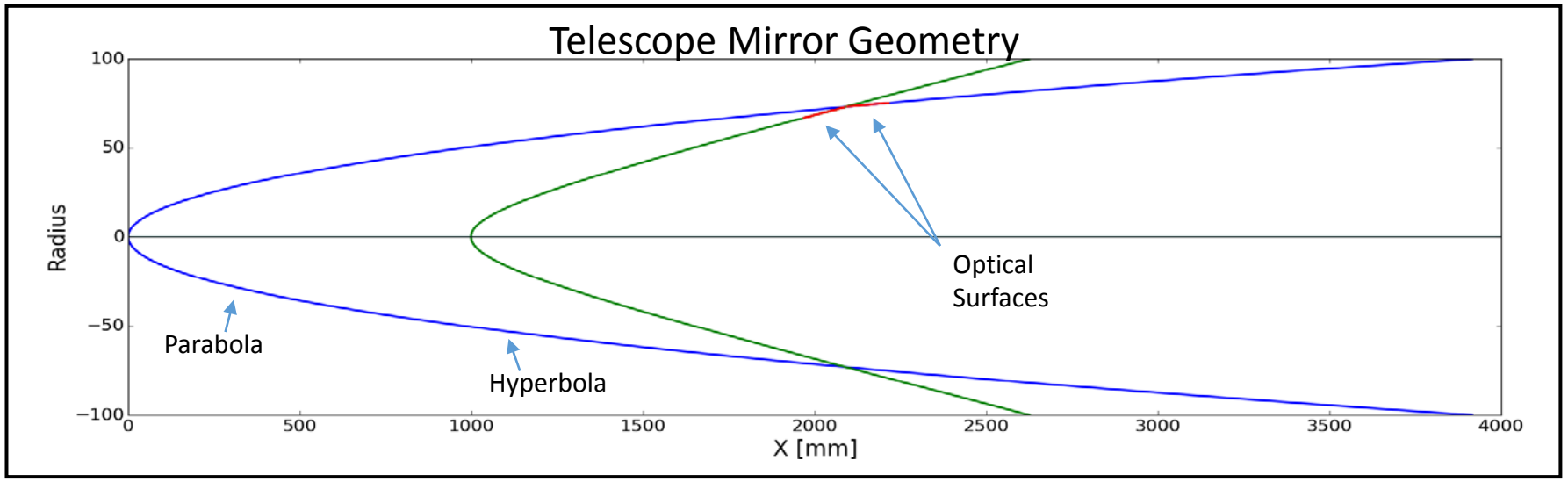
Optical layout



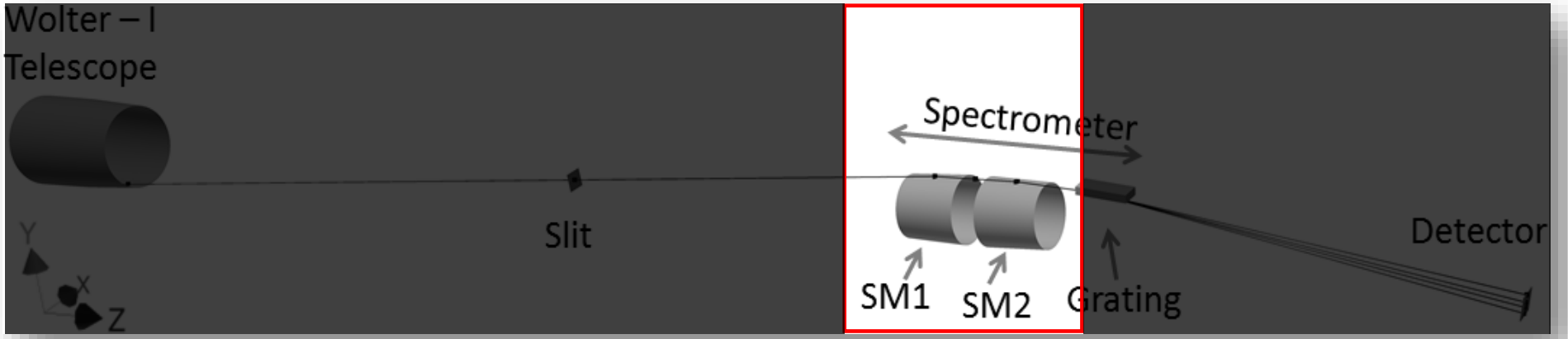
This is what MaGIXS will "see!"

Optical layout

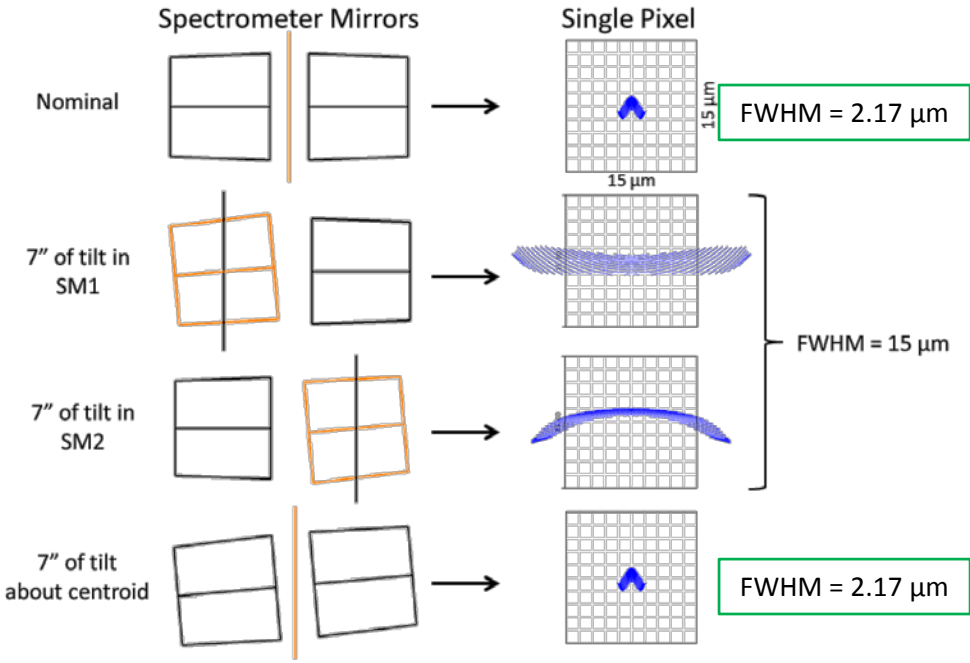
- The **Wolter-I telescope** consists of a paraboloid – hyperboloid combination
  - EFL = 1090 mm, A_G= 960 mm^2, Seg. Len. = 125 mm



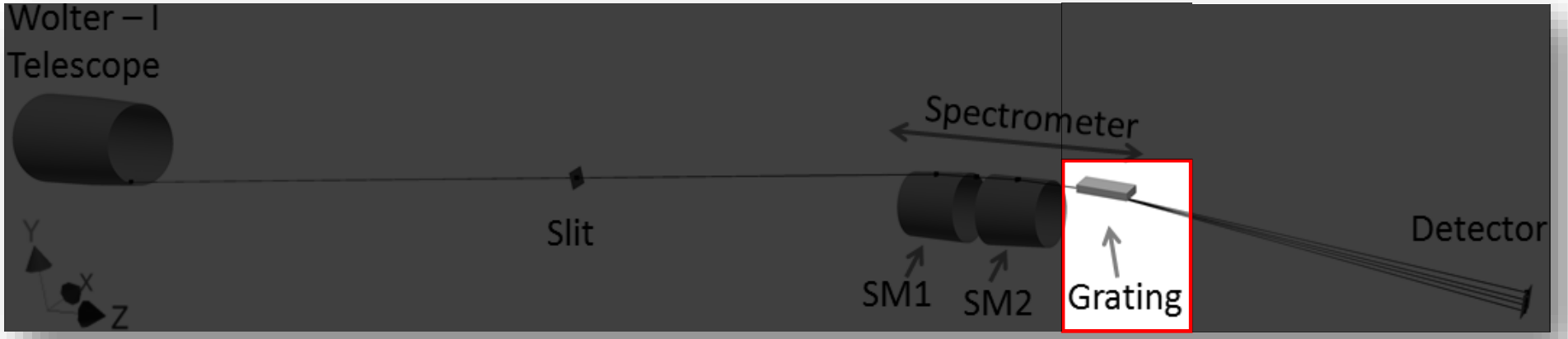
Optical layout



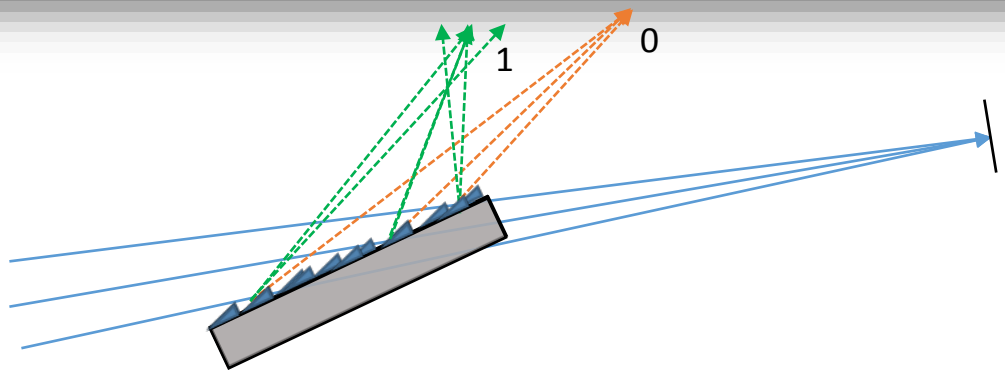
- The **spectrometer mirrors** are a finite conjugate paraboloid pair
  - **SM1** focus is coincident with the slit, which collimates the beam
  - **SM2** reimages that collimated beam
  - This configuration reduces off-axis aberration, specifically astigmatism, giving way to maintaining good resolution off-axis
  - These mirror are highly sensitive to alignment error
- EFL = 652 mm, A_G= 685 mm^2, Seg. Len. = 80 mm

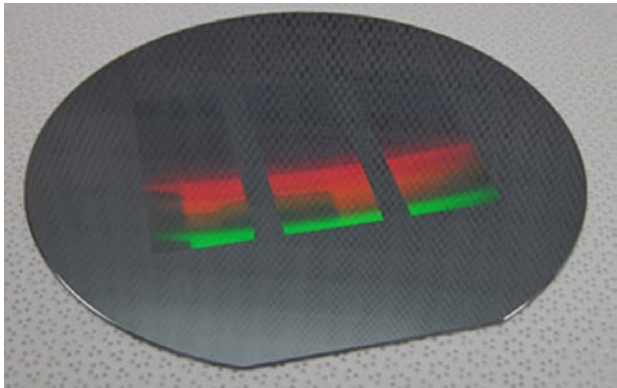


Optical layout

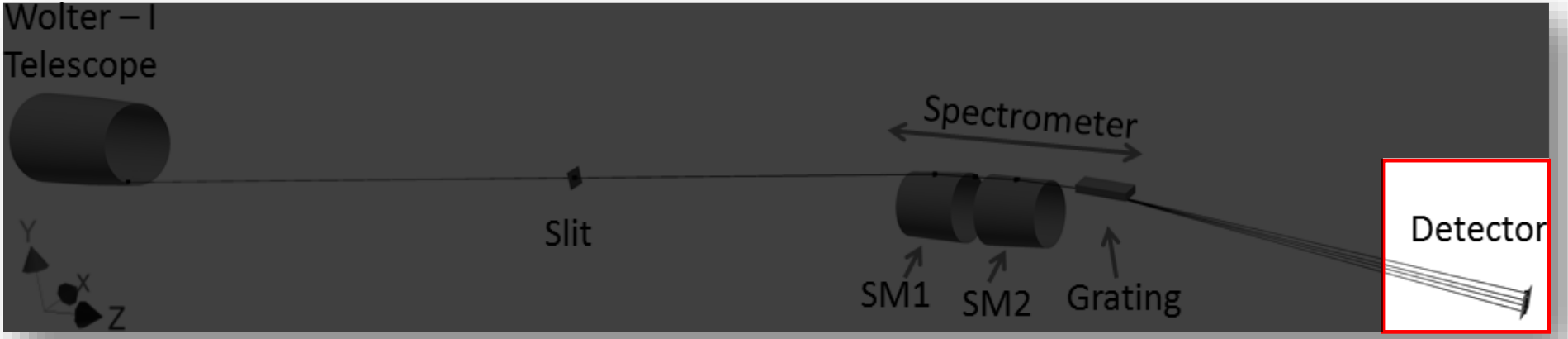


- The **grating** is a varied line space, blazed grating
  - The highly chirped line frequencies direct dispersed wavelengths over varying incident angles to fall at a common location on the detector
  - The chirped line frequencies act as a lens, so alignment is critical
  - The line pattern is directly written on a silicon substrate using e-beam lithography

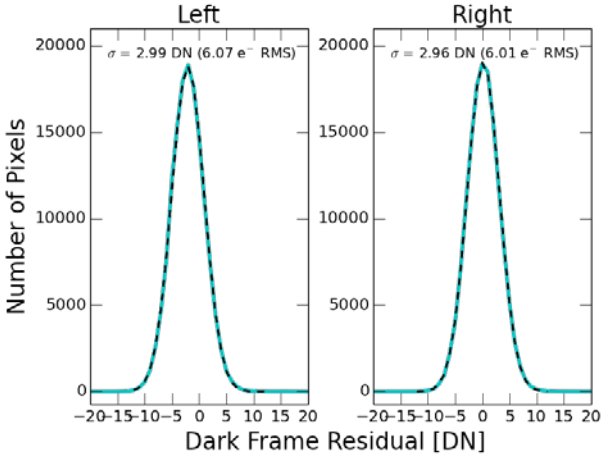


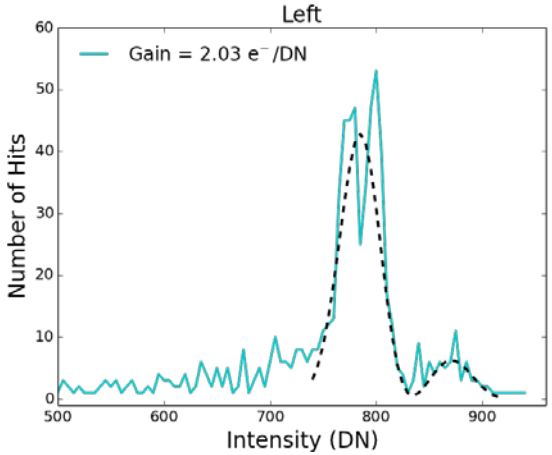


Optical layout



- The **detector** is developed at MSFC and has flight heritage from CLASP and Hi-C II
  - Frame transfer CCD, which enables high-cadence observations
  - Very low dark current (thermal noise)
  - ~ 5 electrons read noise
  - Stable gain of 2.0 e/DN





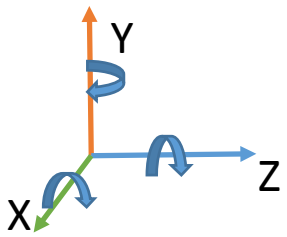
Purpose of Error Budget?

- To demonstrate that if the allowable alignment errors are not exceeded, the system will perform within requirement.

- To understand each component's sensitivity to alignment error.

Independent sources of error

- Each optical element and/or sub-assembly has 6 degrees of freedom
  - Decentering - translation in X, and Y
  - Defocus - translation in Z
  - Tilt – rotation about X, Y, and Z axes
    - Every component, except the grating and the detector, are rotationally symmetric

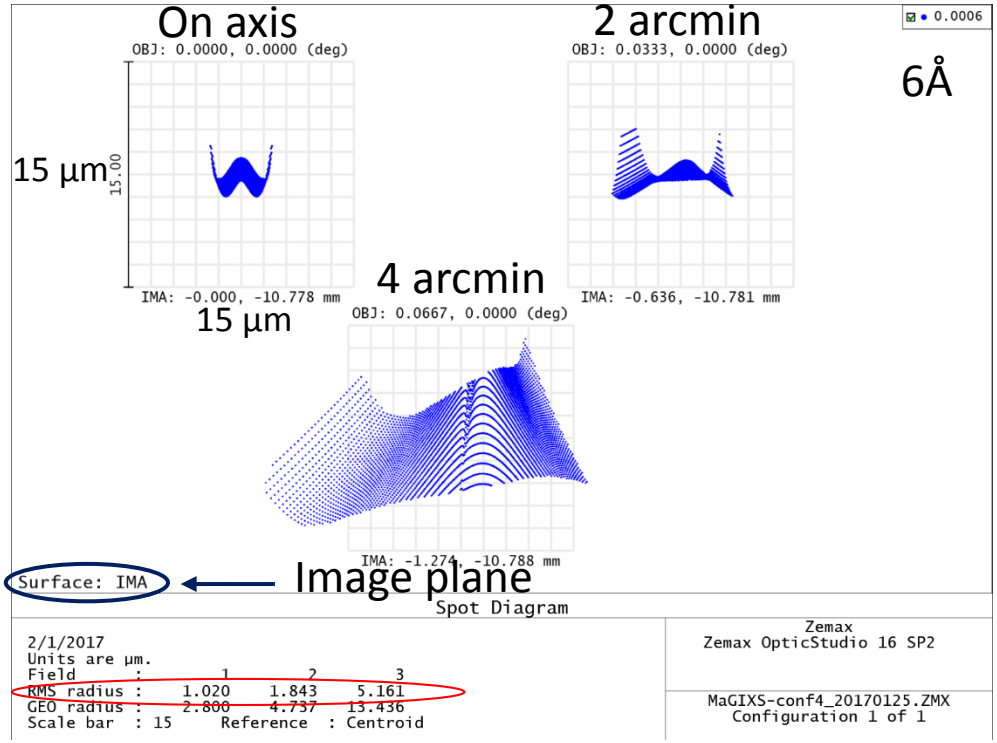


How is the error budget derived?

- Zemax computes the root mean square (RMS) spot radius for each wavelength and field position.

RMS spot radii for each field angle (µm)

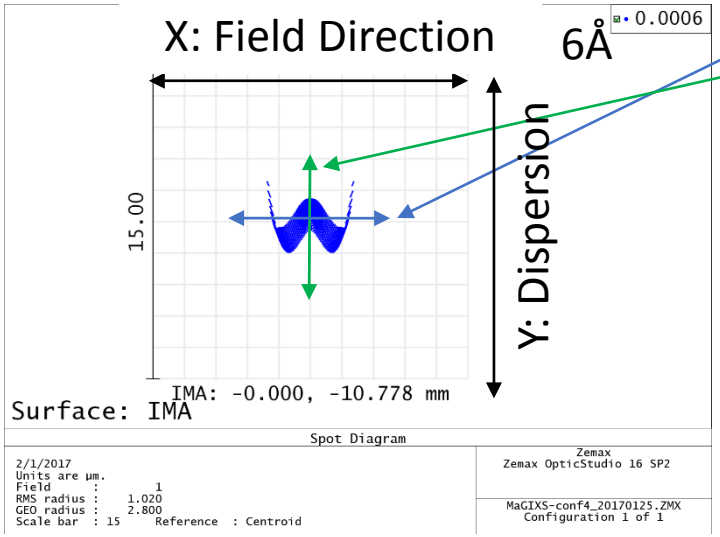
1	2	3
1.020	1.843	5.161



How is the error budget derived?

- The RMS spot X size and the RMS spot Y size are also calculated.

- The RMS spot size in the X direction corresponds to the spatial component
- The RMS spot size in the Y direction corresponds to the spectral component (direction of dispersion)




```
Angle in degrees
Image units: Millimeters
Reference  : Centroid
Reference  : Centroid
Surface    : Image
Wavelength : Monochromatic at 0.0006 µm

                                X                    Y
Field coordinate  :      0.00000000E+00       0.00000000E+00
Image coordinate  :     -3.04160716E-15      -1.07777945E+01
RMS Spot Radius   :      1.02042848E+00 µm
RMS Spot X Size   :      7.71830042E-01 µm
RMS Spot Y Size   :      6.67497317E-01 µm
Max Spot Radius   :      2.80046226E+00 µm

Field coordinate  :      3.33333300E-02       0.00000000E+00
Image coordinate  :     -6.36491873E-01      -1.07805129E+01
RMS Spot Radius   :      1.84340777E+00 µm
RMS Spot X Size   :      1.74181269E+00 µm
RMS Spot Y Size   :      6.03523610E-01 µm
Max Spot Radius   :      4.73732169E+00 µm

Field coordinate  :      6.66667000E-02       0.00000000E+00
Image coordinate  :     -1.27383983E+00      -1.07878061E+01
RMS Spot Radius   :      5.16128156E+00 µm
RMS Spot X Size   :      4.55671377E+00 µm
RMS Spot Y Size   :      2.42387849E+00 µm
Max Spot Radius   :      1.34360111E+01 µm
```

How is the error budget derived?

- Perturb the system by misaligning one component, or subassembly
  - The resulting RMS spot X size and RMS spot Y size are the system's response to the perturbation.
- Record the X and Y RMS spot sizes
- Repeat for each degree of freedom, for each component, or sub-assembly.

How is the error budget derived?

- Compare the resulting RMS spot sizes to the RMS spot sizes produce by the nominal system
  - Take the root difference square (RDS) between the two cases
    - RDS = sqrt($r_p^2 - r_0^2$) → This is the estimated contribution to the RMS spot size, for a given perturbation.

- Take the root sum square of all the RDSs, including the nominal X and Y RMS spot size, to estimate the ~1 sigma performance in the spatial and spectral directions.

$$\text{RSS spot size} = [\Sigma_n \text{RDS}_n^2]^{1/2}$$

Estimated resolution

- The resolution is given as the FWHM
  - For the purpose of the error budget, we assume the spot shape is Gaussian, where $\sigma = RSS_x, RSS_y$
  - FWHM of a Gaussian = $2\sigma \sqrt{2\ln(2)}$ → [µm]
  - FWHM in arcsec → multiply by spatial plate scale: 2.8 arcsec/15µm
  - FWHM in wavelength (Å) → multiply by spectral plate scale (at 6Å end of spectrum): 0.05Å/82.5µm

λ = 6Å

Alignment error budget

X - Spatial Y - Spectral

Field Angles

Element and Error Name		Unit Motion micron or arcsec	On axis RMS Spot Size [µm]				2' RMS Spot Size [µm]				4' RMS Spot Size [µm]				Vignetting Factor (%)
		-	X	RDS(X)	Y	RDS(Y)	X	RDS(X)	Y	RDS(Y)	X	RDS(X)	Y	RDS(Y)	
Nominal		-	0.630	-	0.685	-	1.500	-	0.529	-	4.218	-	3.164	-	0.000
Tscope	Decenter +- X	100	0.760	0.426	0.881	0.554	1.735	0.872	0.666	0.405	4.992	2.669	3.284	0.877	0.197
	Decenter +- Y	100	0.770	0.443	0.887	0.564	1.723	0.848	0.664	0.402	4.905	2.503	3.238	0.687	0.000
	Despace +- Z	100	1.822	1.710	0.789	0.391	2.679	2.220	0.545	0.129	5.257	3.138	3.361	1.132	0.000
	Tilt +- X	30	0.704	0.314	0.851	0.505	1.574	0.477	0.606	0.295	4.269	0.653	3.246	0.723	1.020
	Tilt +- Y	30	0.643	0.129	0.859	0.518	1.640	0.663	0.742	0.520	4.489	1.537	3.687	1.893	0.000
SM1 - SM2 Alignment	Decenter +- X	100	0.630	0.026	0.878	0.549	2.059	1.410	0.628	0.339	5.311	3.226	3.181	0.326	0.000
	Decenter +- Y	100	0.836	0.549	0.886	0.561	1.679	0.754	0.739	0.516	4.456	1.437	3.563	1.637	0.000
	Despace +- Z	100	1.822	1.709	0.792	0.397	2.680	2.221	0.548	0.141	5.248	3.123	3.351	1.102	0.000
	Tilt +- X	8	8.657	8.634	0.880	0.552	9.577	9.459	0.700	0.459	12.138	11.381	3.196	0.451	0.000
	Tilt +- Y	8	2.051	1.952	4.801	4.752	2.312	1.760	4.812	4.782	4.101	0.989	4.519	3.227	0.000
SM1 + SM2 Subassembly	Decenter +- X	100	0.760	0.426	0.881	0.554	1.735	0.872	0.666	0.405	4.992	2.669	3.284	0.877	0.197
	Decenter +- Y	100	0.770	0.443	0.887	0.564	1.723	0.848	0.664	0.402	4.905	2.503	3.238	0.687	0.000
	Despace +- Z	500	0.639	0.107	0.891	0.570	1.489	0.182	0.611	0.306	4.157	0.718	3.160	0.160	0.000
	Tilt +- X	30	0.644	0.132	0.871	0.537	1.516	0.218	0.609	0.301	4.236	0.385	3.256	0.766	0.000
	Tilt +- Y	30	0.643	0.130	0.871	0.537	1.711	0.823	0.668	0.407	4.629	1.906	3.590	1.696	0.000
Grating (Grating Coordinate System)	Decenter +- X	500	0.630	0.000	0.685	0.000	1.500	0.000	0.529	0.000	4.218	0.000	3.164	0.000	0.000
	Decenter +- Y	300	0.773	0.448	1.473	1.304	1.729	0.861	1.095	0.958	4.926	2.544	3.069	0.772	0.197
	Despace +- Z	100	1.154	0.966	0.882	0.555	2.120	1.498	0.681	0.429	5.304	3.215	3.187	0.384	1.775
	Tilt +- X	360	1.183	1.002	0.924	0.621	2.145	1.533	0.712	0.476	5.332	3.262	3.140	0.387	0.394
	Tilt +- Y	360	0.775	0.451	0.889	0.567	1.729	0.860	0.682	0.429	4.930	2.552	3.258	0.776	0.000
	Tilt +- Z	360	0.772	0.447	0.916	0.608	1.720	0.842	0.716	0.483	4.913	2.519	3.356	1.120	0.000
Detector	Decenter +- X	500	0.630	0.000	0.685	0.000	1.500	0.000	0.529	0.000	4.218	0.000	3.164	0.000	0.000
	Decenter +- Y	500	0.630	0.000	0.685	0.000	1.500	0.000	0.529	0.000	4.218	0.000	3.164	0.000	0.000
	Despace +- Z	100	1.821	1.708	0.625	0.280	2.679	2.220	0.511	0.138	5.250	3.125	3.453	1.383	0.000
	Tilt +- X	180	0.739	0.386	0.854	0.509	1.613	0.593	0.591	0.262	4.327	0.963	3.248	0.734	0.000
	Tilt +- Y	360	0.630	0.007	0.878	0.550	1.513	0.202	0.602	0.288	4.243	0.462	3.238	0.688	0.000
	Tilt +- Z	360	0.630	0.000	0.685	0.000	1.500	0.000	0.529	0.000	4.218	0.000	3.164	0.000	0.000
RSS			9.56127		5.53957		11.1232		5.20134		16.0724		6.45477		2.11251
FWHM (µm)			22.5151		13.0447		26.1932		12.2482		37.8477		15.1998		
FWHM (asec)			4.20281		2.43501		4.88939		2.28633		7.0649		2.8373		

Green cells – most sensitive

Estimated FWHM

Vignetting

Mirror Resolution

- The mirror resolution is accounted for by including it in the RSS.
  - Requirement for each mirror:
    - Resolution shall be ≤ 2.0 arcsecs FWHM over a 34 degree sector.

Mirror Resolution	FWHM arcsec	FWHM microns
Telescope	2.0	10.71
SM1	2.0	10.71
SM2	2.0	10.71
RSS	3.4641	18.5577

- RSS is ~3.5 arcsec, or 18.6 microns

Alignment + Mirrors

Estimated Performance	On Axis Field		2 arcmin Field		4 arcmin Field	
	X (spatial)	Y (spectral)	X (spatial)	Y (spectral)	X (spatial)	Y (spectral)
FWHM (μm)	29.18	22.68	32.10	22.24	42.15	23.99
FWHM (X: asec) (Y:Å)	5.45	0.014	5.992	0.013	7.87	0.015

- The estimated FWHM in the spatial and spectral directions
  - Requirement: 6 arcsec FWHM spatial, 0.05 Å FWHM spectral
  - The estimated spatial resolution for the 2 arcmin field position is marginally within the requirement
  - The estimated spectral resolution is well within 0.05Å resolution requirement

Thank you!